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C- and O-Rich Miras and Galactic Structure

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Abstract. This paper summarizes the conclusions of an extensive investigation of variable carbon AGB stars in our Galaxy. The zero-point of the period-M_{bol} relation for Galactic C-Miras is found to be close to that in the LMC. The mean age of Galactic C-Miras is ~ 1.8 Gyr and their initial masses $\sim 1.8 M_{\odot}$ with some evidence that age decreases and initial mass increases with increasing pulsation period. Kinematic studies of Galactic C- and O-Miras show that the relative frequency of these two Miras classes depends on the age of the parent population. The lack of carbon stars in the Galactic Bulge seems to be due to a high oxygen abundance. The velocity dispersion of O-Miras allows one to distinguish between two possible models of Galactic kinematics.

1. Introduction

The kinematics of the large amplitude, oxygen-rich AGB variables known as O-Miras have long been known to give valuable clues to the ages and evolution of AGB stars as well as being important for Galactic structure studies (e.g. Feast 1963; Feast & Whitelock 2000). Until recently the Galactic carbon-rich Miras (C-Miras) have been much less intensively studied. The present paper summarizes the results of a kinematic and photometric study of Galactic C-Miras leading to a determination of their absolute magnitudes and ages. It then goes on to discuss what C- and O-Miras tell us about Galactic structure and composition. The paper is based on three recently published papers (Whitelock et al. 2006; Menzies, Feast, & Whitelock 2006; Feast, Whitelock, & Menzies 2006).

It has been known for a long time that an optically selected sample of C-Miras in the LMC shows a well defined M_{bol} - $\log$ P relation (Feast et al. 1989). It is now possible to extend this relation to longer periods using data for obscured C-Miras (Whitelock et al. 2003). The relation which extends from about 160 to 1000 days has the form

$$M_{bol} = -2.54 \log\ P + 1.87 \tag{1}$$

where the distance modulus of the LMC has been taken to be 18.50mag. The scatter about this relation is only 0.17mag. One aim of the present work was to derive the zero-point of this relation for Galactic C-Miras.

2. Galactic C-Miras: Absolute Magnitudes, Velocity Dispersions and Ages

Multi-epoch JHKL observations were obtained of 239 C-rich variables allowing classification and period determination. Mean bolometric magnitudes were obtained by combining these data with IRAS or MSX observations (details in Whitelock et al. 2006). Combining these results with data in the literature and some new optical radial velocities we have available for analysis 177 C-Miras with known bolometric magnitudes and radial velocities from optical or millimetre (CO) observations (details in Menzies et al. 2006). Assuming a PL relation of the form given in eq. 1, we found clear evidence of differential galactic rotation. The zero-point of this relation was then adjusted until, using a standard formulation of differential rotation, we recovered the Oort constant A derived from Cepheid proper motions (Feast & Whitelock 1997). In this way we obtained a Galactic zero-point of $+2.06 \pm 0.24$, not significantly different from that for LMC C-Miras (eq.1). In the kinematic analysis, we used only stars within $\pm$2kpc of the solar distance from the Galactic Centre. The data are not sufficient to allow us to derive an independent PL slope.

Table 1. Velocity dispersions of C-Miras

Group	Period [days]	α [km s^{-1}]	Age [Gyr]	Mass $M_\odot$	N
All	521	27 ± 2	1.8 ± 0.4	1.8 ± 0.2	149
1	373	32 ± 3	3.1 ± 0.9	1.5 ± 0.2	49
2	521	24 ± 3	1.3 ± 0.5	2.1 ± 0.3	50
3	655	24 ± 2	1.3 ± 0.3	2.1 ± 0.2	50

The residual velocities from differential rotation were then used to derive velocity dispersions. Table 1 shows α, the velocity dispersion radial from the Galactic Centre, for the whole sample and the sample divided by period, as well as the numbers (N) of stars involved. The ages and initial masses were derived using the relation between the kinematics and age of local dwarfs (Nordström et al. 2004) based on Padova models (Girardi et al. 2000). There is some evidence of a trend of age with period, the longer period stars being younger. This is qualitatively similar to the trend of age with period shown by O-Miras (e.g. Feast & Whitelock 2000). The results for the C-Miras contrast with the younger ages and higher initial masses sometimes suggested for the bulk of C-Miras.

3. The Relative Frequency of Cool Carbon- and Oxygen-Rich Stars

In recent years there has been a considerable amount of work based on the hypothesis that the relative frequency of carbon to oxygen rich (M-type) cool stars is a simple measure of the overall metallicity (normally characterized by [Fe/H]) of the stellar system or part of the system in which they are found. The results of the last section allow one to test this in the limited case of the C- and O-Miras and to extend the discussion to cool stars generally.

Table 2. Velocity Dispersions of O-Miras

Period [days]	α [$\mathrm{km\,s^{-1}}$]	N
175	76 ± 8	17
228	69 ± 6	24
272	46 ± 4	26
324	50 ± 4	40
383	45 ± 4	32
453	28 ± 4	15

Table 2 shows the velocity dispersion radial from the Galactic Centre for local O-Miras as a function of period. The data are derived from Feast & Whitelock (2000) and show the dependence of α (and hence age) on period for these stars. A comparison of Tables 1 and 2 shows that there appears to be no significant populations of C-Miras with α in the range 40 to 80 $\mathrm{km\,s^{-1}}$ whilst there are strong O-Mira populations in this range. Since age increases with α, this implies that there are O-Miras in an (old) age range where there is not a significant C-Mira population. Thus the ratio of C- to O-Miras will depend on the age distribution of any population considered and not simply on [Fe/H]. This result may be seen in a somewhat different way for Miras in the solar neighbourhood. For an optically selected sample Wood & Cahn (1977) found that the ratio of the number of O-Miras to C-Miras was about 14. However, in a local sample of dust enshrouded Miras which is biased to longer period (and hence younger) stars this ratio is about unity (Olivier, Whitelock, & Marang 2001).

It is useful to consider in this connection the stellar population of the Galactic Bulge. With one possible exception, this contains no C-Miras or any normal carbon stars. However, it does contain O-Miras with a wide range of periods. These range up to 700 days in the SgrI window (Glass et al. 1995) and to even longer periods near the Centre (Wood, Habing, & McGregor 1998). It has long been known that this implies a considerable age range in the Bulge. The age range implied overlaps with that expected for C-Miras (table 1). This suggests that the absence of C-Miras from the Bulge is not simply an age effect.

In fact, in the past it was usually assumed that the absence of carbon stars in general from the Bulge was due to a high metal abundance. It is, however, now known that Bulge K giants have a mean [Fe/H] of -0.10 and M giants -0.19 (Fullbright, McWilliam, & Rich 2005; Rich & Origlia 2005). These values are close to the mean value for the local thin disc, [Fe/H] $= -0.14$ (Nordström et al. 2004). Thus neither age nor metallicity can apparently explain the absence of carbon stars from the Bulge. However, it has been know for some while (Glass et al. 1995) that the JHK colours of O-Miras in the Bulge differed from those in the LMC and this could be explained by a high oxygen abundance (Feast 1996). Recent work (Rich & Origlia 2005) now shows that in Bulge M giants oxygen is overabundant with respect to comparable local stars ([O/Fe] $\sim +0.3$) whilst several workers find [O/Fe] ≤ 0 in relevant LMC populations. This suggests that oxygen abundance may be a controlling factor in the ratio of carbon to oxygen giants in stellar systems.

The above does not rule out the possible dependence of the relative frequency of carbon stars on [Fe/H] at a given [O/Fe]. If that were the case we would expect that in a system with a spread in [Fe/H] the carbon stars would evolve preferentially from the lower metallicity stars ([O/Fe] assumed constant). However, in the Galactic disc the available work on carbon stars (e.g. Abia et al. 2001) suggests that their [Fe/H] is near that of the mean of local disc stars and not skewed to lower abundances. But further work on this is desirable.

4. O-Miras and the Kinematics of the Galactic Disc

Two alternative interpretations of the kinematics of local disc stars are currently under discussion. Nordström et al. (2004) found that the velocity dispersion of these stars increases steadily with age from 1 to 10 Gyr (see their fig 31 where their σ_U corresponds to the α used in the present paper). On the other hand Quillen & Garnett(2000, 2001) (see also Freeman & Bland-Hawthorn fig 5 where their U corresponds to the α of the present paper) suggest that the velocity dispersion remains constant from 2 to 10 Gyr at about 35km s^{-1} and then jumps suddenly to about 60km s^{-1}, the two regimes constituting the thin and thick discs. This latter interpretation apparently leaves no room for Galactic components with α in the range 35 to 60 km s^{-1} where, as Table 2 shows there is a significant O-Mira population. Since O-Miras are rare objects we expect them to be tracers of a large main sequence population. Such a population is accounted for naturally in the Nordström et al. interpretation of Galactic kinematics. It is, however, difficult to see how it could be accommodated in the Quillen and Garnett model.

5. Summary

1. Assuming the M_{bol} - period relation for Galactic C-Miras has the same slope as for those in the LMC, the zero-points in the two systems are the same within the uncertainties
2. Galactic C-Miras have ages of ~ 1.8 Gyr and initial masses of $\sim 1.8 M_{\odot}$.
3. There is some evidence that the ages of C-Miras decrease with increasing period.
4. The ratio of C- to O-Miras in a population depends on the age distribution of that population.
5. The lack of carbon stars in the Galactic Bulge is connected to an oxygen overabundance.
6. The Galactic O-Miras favour the interpretation of Galactic kinematics of Nordström et al.

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